

FIG. 2

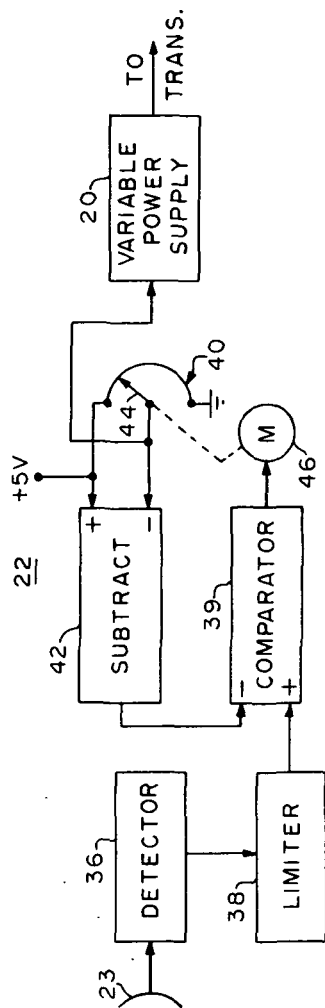
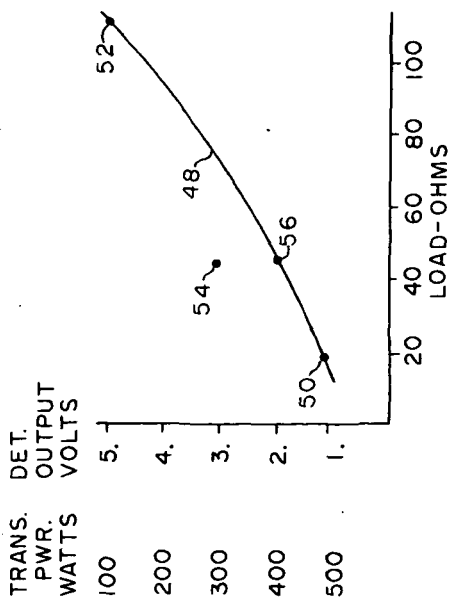


FIG. 3



MICROWAVE POWER TRANSMISSION SYSTEM WHEREIN LEVEL OF TRANSMITTED POWER IS CONTROLLED BY REFLECTIONS FROM RECEIVER

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to systems for the transmission of electrical power by microwave radiant energy.

2. General Description of the Prior Art

It has heretofore been proposed that power be transmitted between otherwise inaccessible locations by microwave radio transmission. Such a method is particularly applicable to the transmission of power through space as between earth and a space station, between earth and the moon or between space stations. Of course, the method is also applicable to transmission of power between locations on earth where the cost or difficulty in building power lines makes transmission by microwave energy feasible.

One difficulty with transmission of power by radio means, particularly where the receiving station is not manned, is that of transmitting correct levels of power, that is levels of power which are needed at a particular time. This is a special problem where there are significant variations in power load at a receiving station. Aside from the waste, problems arise in the dissipation of unneeded energy and in maintaining correct voltage levels.

The applicant is unaware of any previously known systems which effectively provide desired regulation of power between the transmitting and receiving station of such a system.

SUMMARY OF THE INVENTION

Accordingly, it is the object of this invention to provide a microwave power transmission system in which transmitted power is regulated in accordance with power demand and utilization at a receiving station.

These and other objects are accomplished in the present invention in which the transmitting station includes a receiving antenna adapted to receive reflected or reradiated energy from the receiving antenna of the receiving station. The reflected energy increases with non-utilization of energy at the receiving station and variations in received reradiated energy are detected at the transmitting station and employed to regulate the power output of the transmitter of the transmitting station enabling power to be maintained at a level in accordance with actual demands of the receiving station.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be more fully understood by the following detailed description when considered together with the accompanying drawings in which:

FIG. 1 is a schematic illustration of a microwave power transmission system constructed in accordance with the invention.

FIG. 2 is a schematic illustration of a system employed for coupling power from a receiving antenna to a load.

FIG. 3 is a schematic circuit diagram of a power control system for translating a reradiated signal into a control signal for controlling the power of a microwave transmitter.

FIG. 4 is a curve illustrative of the operation of the circuit shown in FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the drawings, there is shown in FIG. 1 a block diagram of a microwave system for transmitting electrical power between a space transmitting station 10 and space sub-station or receiving station 12 wherein transmitting antenna 14 and receiving antenna 16 are precisely aligned for a maximum transfer of energy and are maintained at a precise distance apart. Transmitting station 10 employs a microwave transmitter 18 which is powered by variable or regulatable power supply 20. Power supply 20 is controlled by power control 22 in response to a reflected signal received by auxiliary receiving antenna 23 indicative of the power needed by the receiving station as represented by variable load 25. This is accomplished as follows.

Microwave energy from transmitter 18 is fed to transmitting antenna 14 which is a narrow beam antenna such as a generally elliptical dish-shaped antenna. This antenna is configured to transmit a microwave beam toward receiving antenna 12. Receiving antenna 12 is adapted to receive the transmitted power with maximum efficiency and in accordance with one aspect of the invention would include an array of half wave dipoles 28 supported by and spaced from reflector 30 with dimensions appropriate to capture the maximum amount of electromagnetic energy from transmitting station 12. A power transmission system utilizing this general type of antenna is disclosed in U.S. Pat. No. 3,535,543.

Referring to FIG. 2, dipoles 28 of such an antenna are each terminated at the center by a bridge rectifier 32 which converts radio frequency (R.F.) current to direct current. The outputs of rectifiers 32 are fed to a summing circuit 34 wherein the outputs are appropriately connected in a series parallel circuit arrangement to match the impedance of variable impedance load 25, when load 25 is operating at a maximum power level, that is in a minimum impedance condition.

Receiving antenna 23 is a small directive antenna, mounted near, but positioned in an R.F. null region with respect to, transmitting antenna 14 at transmitting station 10. It samples R.F. energy reflected by receiving antenna 16. The output of antenna 23 is coupled to power control 22 which is adapted to provide a calibrated output signal which is a selected proportional function of the R.F. energy received. This output provides a control signal input to variable power supply 20 which functions to decrease power to transmitter 18, and thus transmitted power, to predetermined values with increased values of reflected energy. In this manner selected equilibrium conditions are achieved between transmitted power and load of variable load 25, and desired amounts of power supplied to variable load 25 for selected discrete load values.

Variable load 25 is typically representative of a combination of powered devices connected electrically in parallel which may all be operated at one time to provide a minimum impedance load or one or more of the devices may be disconnected, or turned off, to provide differing values of higher impedance. The object of this invention is, as indicated above, to transmit less power as fewer devices are being powered, which is signified by increases in load impedance. In this system the quantity of energy reflected at the lowest selected transmitted power (highest impedance-maximum antenna mismatch combination) is greater than with maximum transmitter power with a matched or minimum impedance condition. Thus it is possible to provide a control system which is calibrated in terms of a discrete value of reflected signal for a given load and power level of transmitter 18.

FIG. 3 shows a simplified illustration of a circuit for power control 22. Detector 36 receives R.F. energy from antenna 23 and provides a D.C. output which is fed through limiter 38 to the plus input of comparator 39. A reference voltage, e.g. 5 volts, is connected across potentiometer 40 and to the plus input of subtraction or difference circuit 42. The output of the power control appears on moveable arm 44 of potentiometer 40 and is applied to variable power supply 20 and to the minus output of subtraction circuit 42. The output of the subtraction circuit is connected to the minus input of comparator 39 and the output of the comparator drives reversible arm 44 to thus determine circuit output. Limiter 38, connected between detector 36 and comparator 39, limits the amplitude of signals applied to the comparator to a maximum calibrated output of detector 36 which is equal to the reference voltage.

FIG. 4 shows a graph of detector output voltage plotted versus impedance load conditions. Curve 48 extends between selected operating limits, being between minimum voltage point 50, which is representative of reflected energy with maximum power and a matched impedance load, and a maximum voltage point 52 which is representative of reflected energy with a minimum power but with a maximum impedance, and thus with a maximum impedance mismatch. The output of detector 36 is calibrated in terms of curve 48 which indicates a selected power output for each load value.

To examine operation of the system, it is initially assumed that the system is in equilibrium wherein transmitter 18 is operating with maximum power, e.g. 500 watts, to provide a desired level of power to variable load 25 which is initially providing a matched impedance to receiving antenna 16, e.g. 20 ohms, as shown in FIG. 4. This, as will be noted, is the minimum operating impedance value of load 25. It is further assumed that power supply 20 provides a level of power to transmitter 18 to achieve maximum power output with a +4 volt input from arm 44 of potentiometer 40 and with control arm 44 in the position shown in FIG. 4. It is further assumed that the reflected energy from receiving antenna 16 picked up by antenna 23, and detected by detector 36, provides detector output of +1 volt. Thus, there will be applied to the plus input of comparator 39 a +1 volt. The +4 volt output of control arm 44 is applied to the minus input of subtraction circuit 42 in which this value is subtracted from a reference +5 volts to provide a +1 volt to the minus input of comparator 39. Thus, initially comparator 39 has equal voltages ap-

plied and it provides no output to motor 46 and thus control arm 44 is left at rest and the power level of transmitter 18 is not changed.

It is next assumed that variable load 25 increases in impedance to a value of, e.g. 45 ohms, indicating a decrease in need of power, and from curve 48 it will be noted that this has been fixed at 400 watts. There will then occur an increase in reflected power from antenna 16 which is sensed by antenna 23, causing the output of detector 36 to rise to some value above curve 48, e.g. +3 volts as represented by point 54. This +3 volts is applied to the plus input of comparator 39 and with the +1 volt of the minus terminal there is now a net +2 volts applied to the comparator resulting in a positive output voltage. Motor 46 is then caused to rotate in a direction to cause arm 44 to move downward. As it does, the resulting decrease output voltage of potentiometer 40 is fed to variable power supply 20 reducing the power output of transmitter 18 and power supplied receiving antenna 16. This in turn results in a decrease in reflected power back to antenna 23 and to a reduced output of detector 36. Thus there will occur a decrease in input to the plus input of comparator 39 and an increase in input to the minus input. This occurs since the power supply control voltage on arm 44 decreases, representative of the power output of transmitter 18, and this voltage is subtracted from the +5 volts reference voltage. When the voltages applied to comparator 39 are equal, which will occur at intersection point 56 on curve 48, the output of comparator 39 will again be made zero, turning off motor 46 and a new desired power level will have been achieved.

Since detector 36 is appropriately compensated and calibrated as illustrated by curve 48 to provide an output which varies generally in proportion to load for each power setting, this means that between the operating limits of the system, that for each load value there exists a coordinate power level. If the power level is too high, the output voltage of detector 36 will be above that indicated by curve 48 and whenever there is insufficient power for a given load, the output voltage of detector 36 will be below curve 48. If the detector output for a given load is below curve 48, the net error voltage applied to comparator 39 will be negative and motor 46 will be turned in a direction to cause arm 44 to provide a higher voltage and to cause power supply 20 to effect a higher output from transmitter 18. An opposite polarity output of detector 36 produces an opposite effect, to lower transmitter power.

It is to be appreciated that the control circuit of power control 22 illustrated in FIG. 3 is illustrative of only one circuit for this purpose and that various systems of adjusting the power of transmitter 18 responsive to the reflected energy from receiving antenna 16 may be employed to provide a particular power output of transmitter 18 for a particular load condition.

What is claimed is:

1. A microwave power transmission system comprising:
 - a microwave power generator;
 - power supply means responsive to an input control signal for providing variable operating power to said microwave power generator whereby said microwave power generator is caused to provide an output of a selected level of microwave energy;
 - a power transmitting antenna adapted to receive power from said microwave power generator and

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direct microwave energy in an energy beam in a selected direction;
a power receiving antenna spaced from said power transmitting antenna and being positioned and oriented to receive maximum energy from said transmitting antenna;
a variable impedance, electrical, load connected to receive and use energy from said power receiving antenna;
a second power receiving antenna positioned near said transmitting antenna and adapted to receive electrical energy reflected from said first power receiving antenna;
control means responsive to the output of said second power antenna for providing said control signal to said power supply means;
whereby said power supply means is controlled and

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the output of said microwave power generator coordinately controlled in accordance with power requirements of said variable impedance load.

2. A microwave power transmission system as set forth in claim 1 wherein said control means is operable for providing variable control signals responsive to load values variably between a load value substantially equal to the impedance of said power receiving antenna and a selected impedance value greater than the impedance of said power receiving antenna.

3. A microwave power transmission system as set forth in claim 2 wherein said control means includes means responsive to selected combinations of load impedance-power levels of the system for providing said control signal and selected transmitter outputs for selected values of said variable impedance load.

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